UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DOE Based Modeling In Machining Application

Thesis submitted in accordance with the requirements of the Technical University of Malaysia Melaka for the Bachelor Degree of Manufacturing Engineering in Manufacturing Process

By

Mohd Ridzuan Bin Mustapha

Faculty *of* Manufacturing Engineering

April 2007

DOE BASED MODELING IN MACHINING APPLICATION

MOHD RIDZUAN BIN MUSTAPHA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS TESIS*

JUDUL: DOE BASED MODELING IN MACHINING APPLICATION

SESI PENGAJIAN: 2006/2007

Saya MOHD RIDZUAN BIN MUSTAPHA

(HURUF BESAR)

mengaku membenarkan tesis (PSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

- [ ] SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)
- [ ] TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
- [√] TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

Alamat Tetap:
412, Kg. Selising Tmur,
16810, Pasir Puteh,
Kelantan.

Cop Rasmi:
SIVARAO
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

Tarikh: 09/05/2007

Tarikh: 14/5/07.

* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertai bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab d[illegible]kan sebagai SULIT atau TERHAD.

APPROVAL

This thesis submitted to the senate of UTeM and has been accepted as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process). The members of the supervisory committee are as follow:

Signature : …………………

Supervisor : MR. SIVARAO

Date : 9TH MAY 2007

DECLARATION

I hereby, declare this thesis entitled

"DOE Based Modeling In Machining Application"

is the results of my own research except as cited in the reference.

Signature : ....

Author Name : MOHD RIDZUAN BIN MUSTAPHA

Date : 14/05/07

ABSTRACT

This paperwork presents the used of the Design of Experiment method in machining application that scoped on the laser cutting machine. In this project, the improvement planning is focused on the laser cutting machine parameters. The experimentation purposes is to optimize the machining parameters where it required determination of how changing the value of one variable or measurement can affect another variable. Another purpose of experimental design is to determine the significant factor and insignificant factor which influence the quality of a product manufacture by laser cutting machine. Besides, some parameters of the machining process can be aliased to reduce the machining cost and if the experiment is well design, it can eliminate all possible causes. In this experimentation, it is focused on the laser cutting machine where it will be experimented by manufacture products to measure the edge quality of each product. The material selected is mild steel (RST37-2) with two different thickness 2.5mm and 5mm that are fixed for the whole experiment. Before run the experimentation, a factorial design matrix is create to determine the number of experimentation run and this is doing by analyzed the early output data through testing that had been doing to get the best setup value for each parameters. From this step, it had been determine to use the 2-level Full Factorial design and the real experiment on the machine can be run. Then, the output data, surface roughness, Ra value will be derived from measuring the workpiece surface by using Portable Surface Roughness Tester. The response data (surface roughness value) of the experiment will be collected and been insert into the design table to analyzed factorial design in determination of the significant factors. For different thickness, it has different parameters that influence the cutting edge quality. For 2.5mm, their significant parameters are gas pressure and cutting speed while for 5mm it has gas pressure, power and cutting speed as their main effects. Optimization can be done if there is insignificant factor like focal distance be discard from the machining process without effect on the edge quality of machining product

ABSTRAK

Kertas kerja ini mempersembahkan kegunaan kaedah rekabentuk eksperimen dalam aplikasi permesinan khusus kepada mesin pemotongan laser. Dalam projek ini, perancangan pembaikan adalah tertumpu kepada parameter mesin pemotongan laser. Tujuan eksperimen ini adalah untuk mengoptimumkan parameter permesinan dimana ianya diperlukan untuk menentukan bagaimana dengan mengubah nilai parameter sesuatu pembolehubah atau pengukuran dapat mempengaruhi pembolehubah yang lain. Tujuan lain rekabentuk eksperimen ini adalah untuk menentukan factor penting dan factor yang tidak penting dimana ianya mempengaruhi kualiti sesuatu produk yang dihasilkan meggunakan mesin pemotongan laser. Disamping itu, beberapa parameter dalam proses permesinan boleh diketepikan untuk mengurangkan kos permesinan dan jika ekserimen itu direkabentuk dengan baik, ianya akan dapat menghapuskan semua kemungkinan punca masalah. Dalam eksperimen ini, ia tertumpu kepada mesin pemotongan laser dimana ia akan melalui eksperimen yang menghasilkan produk untuk mengukur kualiti sisi sesebuah produk. Bahan yang dipilih adalah besi lembut (RST37-2) dengan dua ketebalan yang berbeza 2.5mm dan 5mm yang mana ianya adalah tetap sepanjang eksperimen. Sebeelum eksperimen dijalankan, sebuah matriks rekabentuk factorial dicipta untuk menentukan jumlah jenis-jenis eksperimen dan ini dilakukan dengan mnganalisa data keluaran awal melalui beberapa percubaan untuk mendapatkan nilai bentuk yang terbaik untuk setiap parameter. Daripada langkah ini, ianya telah ditentukan untuk meneruskan eksperimen dengan menggunakan ‘2-level full factorial design’. Kemudian data keluaran atau data perolehan, kekasaran permukaan, nilai Ra akan didapati daripada pengukuran permukaan benda kerja dengan menggunakan ‘Portable surface roughness tester’. Data respon (nilai kekasaran permukaan) eksperimen akan dikumpulkan dan dimasukkan kedalam jadual rekabentuk menganalisis rekabentuk factorial dalam menentukan factor-faktor penting. Untuk ketebalan benda kerja berbeza, ianya mempunyai parameter penting yang berbeza yang mempengaruhi nilai kekasaran permukaan. Untuk ketebalan 2.5mm, parameter-parameter pentingnya adalah tekanan gas dan kelajuan pemotongan manakala untuk ketabalan 5mm ianaya mempunyai tekanan gas, kuasa da kelajuan pemotongan sebagai kesan utama. ‘Optimization’ boleh dibuat bilamana terdapat factor yang tidak penting yang boleh diketepikan seperti jarak fokal daripada prose permesinan tanpa kesan pada kualiti sisi atau kualiti kekasaran permukaan pada sesuatu produk permesinan.

ACKNOWLEDGEMENT

Thanks to the Almighty that give me permission to complete and finish this project paperwork. I wish to express my appreciation to those who have aided in the completion of this task. I also would like to send my regard to my parent that has made many contributions for me by supporting me from behind. Best regard to my supervisor P.S. Sivarao for all of helped and guidance to me. I would like to acknowledge him for provided many helpful comments that greatly influence the overall project completion. I also would like to acknowledge Mr. Johnny Purnomo as my second supervisor for his responsibilities in supervising me. I am glad to acknowledge my colleagues that had helped me and involved in this thesis built. Lastly, I would like to thank all the staff of UTeM, especially the technician of manufacturing workshop that have guide and help me in doing the experimentation, manufacturing faculty staff and all the people that contributes in this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

ANOVA	-	Analysis of Variance
CO_2	-	Carbon Dioxide
DF	-	Degree of Freedom
DOE	-	Design of Experiment
DPSSL	-	Diode pumped solid-state laser
F.D.	-	Focal Distance
HAZ	-	Heat Affected Zone
Hz	-	Pulse frequency
J	-	Pulse energy
J/cm^2	-	Laser energy over area
KPIV's	-	Key Performance Input Variables
KPOV's	-	Key Performance Output Variables
mm/s	-	Cutting speed
N_2	-	Nitrogen
O_2	-	Oxygen
OFAT	-	One Factor-at-a –Time
QFN	-	Quad Flat No-ead
Ra	-	Surface Roughness
RSM	-	Response Surface Method
R^2	-	R-Squared
R-Squared	-	Relative Significance
SS	-	Sum of Squares
S.O.D.	-	Stand-off Distance
S/N	-	Function of Signal to Noise
W	-	Watt, Laser power intensity
X's	-	Input Variables
Y's	-	Output Variables
Y = f(x)	-	Mathematical Model

CHAPTER 1

INTRODUCTION

1.1 Background of the Project

Nowadays, experimental design has been so familiar where it had been practically being applied in the big company and factory worldwide. It had been successfully brought rapid improvement to the process that goes through this implementation. There are some method of experimentation which it were consist of two kinds where how most people do experiment and how the expertise one doing. If the experimental was well-designed, it can eliminate all possible causes except the one's that been tested. To relate the operating variables and characteristics of the laser to the parameters affecting the cut quality, many models have been developed over the years for the laser cutting process. Modeling provides considerable insight into the interaction mechanisms.

The need to establish the laser processed parts that satisfy all functional requirements of the application as a uniform surface finish, low roughness and the conservation of their metallurgic properties was the main motivation in the accomplishment of this study. Besides the versatility and advantages, as well as the industrial sector global trend, became important factors in the lasers use as machining tools. The scope of present study was to investigate the effects of laser processing on the quality and formation of phases in the cut surface. A factorial arrangement regarding the several combinations of different processing factors was built and the influence of these specific parameters, which were statistically significant for the process, was evaluated by the analysis of variance statistical test.

1.2 Problem Statement

Every industry inserted in the production chain aims a continuum enhancement on their processes control and also on their products development. The factors such as quality, reliability and costs reduction are important motivations for the operational excellence achievement serving also to generate competitive items in the global scenario. Consequently, these factors may be the basis of choosing the laser processing replacing the conventional methods. This procedure includes several segments in different areas where the laser is focused by the main industrial applications such as cutting, drilling, welding, thermal treatment and marking.

The applications for the laser material processing involves mechanisms on which it becomes necessary to adequate the type of material and its geometrical shape to the laser type (which is determined by the wavelength and the continuous or pulsed operation mode). From this selection it is also necessary to choose and set the various process parameters that influence on the final result quality, cost and speed, among others factors. This technology stimulates major interest due to the fact that it joins various advantages such as: non contact process and no tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on the beam delivering, simplicity in fixation, easy automation, small heat affected zone, high speed, excellent edge quality.

Laser cutting is now a popular process in most manufacturing industries. Both metallic and nonmetallic materials are cut, welded, and surface treated by different types of lasers at different operating powers. This paper aims to study the capability of low power laser to perform tasks other than marking. A theoretical model is developed to estimate the depth of cut with the cutting speed and laser power for different materials. The agreement between theoretical and experimental results is investigated for different range of materials. A semi-empirical equation is introduced either to assist to optimize the cutting process or to determine the required capacity for the selection of the laser.

Laser cutting is probably the most widely used laser processing technology. There are still many problems that are not well-understood in laser cutting. Besides, laser cutting machine cost is highly in the market now because of its components and part that difficult to built. Although by using laser cutting machine, it can produce good quality product with faster machining process and this advantages make the requirement of it in manufacturing field increase. But, there still some weakness of using this machine where because of it's high cost, the maintenance of this machine also too high.

In this machine there are some common components or parameters that are always being used during the part producing. All of these machine parameters are contribute and will influence the quality of the product that being produced. But, the levels of influence for each parameter are different which there are some parameters that greatly influence the output or quality of product which significant to the process. There is also some machining parameters that only have small influence to the machining process and quality of the product where if these parameters are neglect the quality of the product is not much influence by it. In this condition, if there is no contribution of parameters it can be state as some machining waste because the using of this parameters cost much in the machining process. So, the parameters can be cut away from the machining process to avoid this waste.

Then, there must be some kinds of analysis to determine which parameters are not contribute much and which parameters are the significant factors in the machining process. Mathematical modeling of laser cutting is essential for improved understanding of the process. A variety of overviews have appeared over the last decade, with guidelines and data for laser cutting of various types of materials Additional modeling endeavors have extended the level of analysis to incorporate other factors such as reactions between the assist gas and cutting front, and dynamic effects of striation formation. The variation of material absorptive is also an important factor in laser cutting for which some investigations have been conducted in recent years. The modeling of laser cutting generally attempts to evaluate the cutting quality for given conditions or to estimate the cutting capability for a given laser and material.

1.3 Project Objective

The specific objectives for Design of Experiment Based Modeling in Machining Application for this project are:

i.) To investigate the capabilities of laser cutting machine parameter to obtain a good quality cutting.

ii.) To study about the experimental method and it function for machine application.

iii.) To study the significant factors of machining parameter in developing improvement for machining process.

1.4 Project Scope

We are concerned with the analysis of data generated from an experiment. It is wise to take time and effort to organize the experiment properly to ensure that the right type of data, and enough of it, is available to answer the questions of interest as clearly and efficiently as possible. This process is one type of experimentation which called experimental design. There are many types of experimental design that are commonly used and in these study it focused on the Design of Experiment type which are highly prove that produce accurate determination of the process analysis improvement.

Nowadays, many company and factory that involve in manufacturing field have applied this experimentation method in their process improvement methodology which is expand by Toyota company that got above 30% profit per year by reduction cost of their process improvement. This method is applied in all field and part. Mostly many improvements that have been implemented are in manufacturing field and process which involve the improvement for machine, workers, systems and others. In this study, the experimental design was focused on machining application and the machine that involve is laser cutting machine.

The first statistician to consider a methodology for the **design of experiments** was Sir Ronald A. Fisher. He described how to test the hypothesis that a certain lady could distinguish by flavor alone whether the milk or the tea was first placed in the cup. While this sounds like a frivolous application, it allowed him to illustrate the most important means of experimental design:

- Randomization - The process of making something random
- Replication - repeating the creation of a phenomenon, so that the variability associated with the phenomenon can be estimated
- Blocking - the arranging of experimental units in groups (blocks) which are similar to one another
- Orthogonally - Means perpendicular, at right angles or statistically normal.
- use of factorial experiments instead of the one-factor-at-a-time method

Analysis of the design of experiments was built on the foundation of the analysis of variance, a collection of models in which the observed variance is partitioned into components due to different factors which are estimated and/or tested. In 1950, Gertrude Mary Cox and William Cochran published the book *Experimental Design* which became the major reference work on the design of experiments for statisticians for years afterwards. Developments of the theory of linear models have encompassed and surpassed the cases that concerned early writers. As with all other branches of statistics, there is both classical and Bayesian experimental design that are provided.

In this condition, the experimentation is implemented on this machine because laser cutting machine have high maintenance cost. From this view, it can cause inner profit if the cost can be reduced and the improvement being control. For laser cutting machine, there are types of parameter that consist of fixed and variable parameters. In this case, there are some factors or parameters that significant to the machining process which can produce good quality of product and there also parameters that influence the process a little bit only. For variable parameters that not contribute to the process much, it can be remove from the process differ to the fixed parameter that can’t be changed. If those parameters are removed from the machining process, it can reduce the cost of product machining and it can be removed if the process and quality of the product still the same or have only a little bit of change.

CHAPTER 2

LITERATURE REVIEW

The objective of experimental design is to provide the researcher or a practitioner with a statistical method that determined which input variables are most influential on the output and where to set the influential input variables so that the output is either maximized, minimized or nearest to a desired target value. The design of experiment approach can be applied to the objectives that are as follows; smallest-is-the-best, larger-is-the-best or nominal-is-the-best. One of the essential ideas underlying a designed experiment is that some methods of collecting input and output data are more powerful that others. The method of analyzing one input variable at a time, while holding the others fixed, turns out to be the least effective design. In a statistically designed experiment, the practitioner is able to change the much needed and often desired multiple variables to determine the impact of the response.

Though the design of experiment concepts has long been used in the sciences, industry has not caught on with these methods since their introduction in 1940s. In recent years, however design of experiments has gain great popularity, primarily because of its great success in Japan when it was introduced by W.E.Deming [57]. While Sir Ronald A. Fisher [2-4] was clearly the pioneer in the use of statistical methods in experimental design, there have been many other significant contributors to the literature of experimental design, including F. Yates [58-60], R.C. Bose [61], to name a few.

The applications for the laser material processing involves mechanisms on which it becomes necessary to adequate the type of material and its geometrical shape to the laser type (which is determined by the wavelength and the continuous or pulsed operation mode). From this selection it is also necessary to choose and set the various process parameters that influence on the final result quality, cost and speed, among others factors [11] and [27]. This technology stimulates major interest due to the fact that it joins various advantages such as: non contact process and no tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on the beam delivering, simplicity in fixation, easy automation, small heat affected zone, high speed, excellent edge quality.

An attempt to improve such properties surface engineering may cause some difficulties to the conventional machined methods such as: high tool wear, processing time and operational costs. Both metallic and nonmetallic materials are cut, welded, and surface treated by different types of lasers at different operating powers. Coherent [17] reported that a 500 W CO_2-laser was used to cut nylon seat belts. The laser operated at a cutting speed of 20 mm/s. It was also reported that a 275 W CO_2-laser was used with a 254 mm focal length lens and a coaxial gas jet to cut 114 mm thick rubber foam at a speed of 16.6 mm/s. Peters [15] investigated the application of lasers in cutting wood. A 1 kW CO_2-laser was used with an assisted N_2 gas jet. Furthermore, Todd [28] reported that a 560 W CO_2-laser beam can remove ceramic materials at a rate of 5.3 mm^3/s. Numerous theoretical models for laser machining have been development by researchers.

There are still many problems that are not well-understood in laser cutting. Mathematical modeling of laser cutting is essential for improved understanding of the process. A variety of overviews have appeared over the last decade, with guidelines and data for laser cutting of various types of materials [10 and 44]. Laser cutting models are generally based on energy balance and the solution of a set of heat transfer equations to obtain a detailed temperature field evolution [36,45,46,48 and 50]. Additional modeling endeavors have extended the level of analysis to incorporate other factors such as reactions between the assist gas and cutting front [16,38 and 47], and dynamic effects of striation formation [30]. The modeling of laser cutting generally attempts to evaluate the cutting quality for given conditions [13 and 26] or to estimate the cutting capability for a given laser and material [8].

Previous mathematical models on laser beam cutting have involved fluid dynamics and heat transfer phenomena [12]. Arata et al. [52] discovered that the cutting speed was less than the speed of the moving molten layer, caused by the oxidation. Jae et al. [29] developed a 1-D with transient mathematical model for the prediction of striation formation in a reactive gas assisted laser cutting process. Reactive heat for oxygen cutting and the evaporation mechanism have been considered by Schuőcker [21] to calculate the dynamic phenomena responsible for the striation on the cut surface. The model deals with both the physical and chemical states at the cut front describing the characteristics of striation..

However, the existing models are not sufficient to fully demonstrate the dynamic behavior of laser cutting and the formation of periodic striations as shown in Fig. 1. Most of the models only relate the molten metal layer with constant cutting speed or constant laser power; no interactions are given for the time-dependent factors. In this paper, an analytical is developed to enable the analysis of the formation of molten layer, considering a number of process parameters. The enclosed area between melting front and cutting front is defined as the control volume (cv). Balance of mass, momentum and energy are integrated over the system boundaries in order to predict the melt film thickness, its displacement and velocity, laser absorption and cutting front temperature. The proprieties of the interfaces between the gas and liquid and liquid and solid are considered within the model.

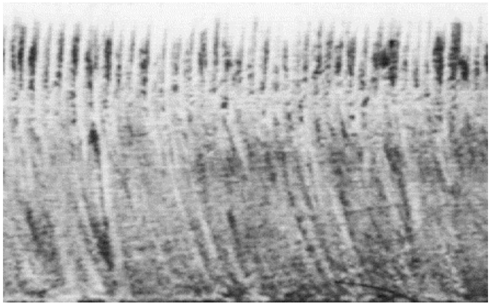

Fig. 1: A typical cut edge mild steel showing the periodical striation

The process thickness for metals is mainly in the range of 1–6 mm, but the capability can extend beyond 25 mm (a cutting performance up to 120 mm sheet thickness has been achieved with a 2.5 kW CO_2 laser [51]. O'Neill and Steen [49] remark that "Process windows are empirically well defined […]. The need to develop mathematical models of the laser cutting process is still very real since quality demands placed on the process by industry are ever increasing as are the cost of experimental trials."